SEMICONDUCTOR MECHANICAL QUANTITY SENSOR

CROSS REFERENCE TO RELATED APPLICATIONS

This application is based upon, claims the benefit of priority of, and incorporates by reference the contents of Japanese Patent Application No. 2003-65836 filed on March 12, 2003.

FIELD OF THE INVENTION

This invention relates to a semiconductor mechanical quantity sensor for detecting the mechanical quantity such as acceleration based on the capacities among fixed electrodes and moving electrodes.

BACKGROUND OF THE INVENTION

A semiconductor mechanical quantity sensor has been disclosed in, for example, JP-A-5-304303. A mono-axial (X-direction) capacitor-type acceleration sensor will be generally described with reference to Figs. 3A – 3C. Grooves 11 are formed in a semiconductor layer of a semiconductor substrate 10 such as of silicon, whereby a plurality of pairs of fixed electrodes 1 and moving electrodes 2 are opposed to each other in the X-direction to constitute capacitors. The moving electrodes 2 are formed in a plurality of pairs like a comb teeth in the ±Y-direction with respect to a weight 3 extending in the X-direction. Both ends of the weight 3 are formed on the semiconductor substrate 10 so as to undergo a

1

displacement in the X-direction, and beams 4 of a two-piece structure are formed at both ends of the weight 3 so as to undergo the displacement depending upon the acceleration. The fixed electrodes 1 arranged in the $\pm Y$-direction so as to be opposed to the moving electrodes are connected to pads 5a and 5b made of aluminum or the like, and the moving electrodes 2 are connected to a pad 5c. The pads 5a, 5b and 5c are connected to an external unit through pads 6a, 6b and 6c of another circuit chip 6 such as a mother board by bonding using wires W.

Here, a moving electrode 2a is arranged between the neighboring fixed electrodes 1a and 1b. When an acceleration in the X-direction is exerted on the sensor of this constitution, the beams 4 are displaced in the X-direction, whereby distances vary among the fixed electrodes 1a, 1b and the moving electrode 2a, causing a change in the capacity CS1 between the fixed electrode 1a and the moving electrode 2a and in the capacity CS2 between the fixed electrode 1b and the moving electrode 2a. An equivalent circuit of the semiconductor mechanical quantity sensor is illustrated on the left side in Fig. 4. A pulse voltage Vcc has been applied across the fixed electrodes 1a and 1b. A change ΔC (= CS1 – CS2) in the capacities CS1 and CS2 that has occurred is taken out from the moving electrode 2, and is converted into a voltage = (CS1 – CS2) · Vcc/Cf through, for example, a switched capacitor circuit 5 illustrated on the right side in Fig. 4 to thereby detect the acceleration.

In order to improve the sensitivity of the sensor, so far, it was attempted to soften the spring constant kw by varying

2

the sizes of beams 4, electrodes 1, 2, and weight 3 of the comb teeth structure, by increasing the mass m or by increasing the capacity C0. Figs. 5A - 5C illustrate a structure in which the beams 4 are folded twice to soften the spring constant of the beams 4 to be one-half in an attempt to double the sensitivity.

However, the resilient restoring force < electrostatic force between the fixed electrodes 1 and the moving electrodes 2 involves a problem of easy sticking. Further, the circuit chip, too, easily undergoes the displacement in the vertical direction (Z-direction). When a large shock is exerted in the Z-direction, therefore, the moving electrodes 2 ride on the fixed electrodes 1 and become no longer capable of moving. Also, the dynamic range narrows.

SUMMARY OF THE INVENTION

In view of the above-mentioned problems, it is an object of this invention is to provide a semiconductor mechanical quantity capacitor which features high sensitivity free of sticking.

In order to achieve the above object according to this invention, there are arranged, in the same direction, a plurality of mono-axial sensors for detecting a mono-axial mechanical quantity based on capacities among fixed electrodes and moving electrodes coupled to beams that are capable of undergoing displacement depending upon the acceleration.

The above constitution makes it possible to improve the sensitivity by a plurality of number of times without causing

sticking.

When the output of a single sensor is doubled, the noise component, too, is doubled and the S/N ratio does not vary. According to this invention using two sensors, however, the output of signal component only is doubled while the noise component remains unchanged. Therefore, the S/N ratio is improved twice as much (noise occurs in a random fashion and is not superposed).

BRIEF DESCRIPTION OF THE DRAWINGS

The above and other objects, features and advantages of the present invention will become more apparent from the following detailed description made with reference to the accompanying drawings. In the drawings:

Fig. 1A is a plan view of a semiconductor mechanical quantity sensor according to a preferred embodiment, Fig. 1B is a sectional view along the line IB-IB of Fig. 1A, and Fig. 1C is a sectional view along the line IC-IC of Fig. 1A;

Fig. 2A is a plan view of a semiconductor mechanical quantity sensor according to a modification, Fig. 2B is a sectional view along the line IIB-IIB of Fig. 2A, and Fig. 2C is a sectional view along the line IIC-IIC of Fig. 2A;

Fig. 3A is a plan view of a related art semiconductor mechanical quantity sensor, Fig. 3B is a sectional view along the line IIIB-IIIB of Fig. 3A, and Fig. 3C is a sectional view along the line IIIC-IIIC of Fig. 3A;

Fig. 4 is a circuit diagram illustrating an equivalent

4

circuit of the related art semiconductor mechanical quantity sensor and a switched capacitor circuit;

Fig. 5A is a plan view of a related art semiconductor mechanical quantity sensor, Fig. 5B is a sectional view along the line VB-VB of Fig. 5A, and Fig. 5C is a sectional view along the line VC-VC of Fig. 5A;

Fig. 6 is a circuit diagram illustrating an equivalent circuit of the semiconductor mechanical quantity sensor of Fig. 1A and a switched capacitor circuit; and

Fig. 7 is a circuit diagram illustrating an equivalent circuit of the semiconductor mechanical quantity sensor of Fig. 2A and a switched capacitor circuit.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

An embodiment of the invention will now be described with reference to the drawings.

Figs. 1A – 1C illustrate an embodiment in which two sensor chips 100a and 100b, which have the same structure and the same characteristics, are formed in semiconductor substrates 10a and 10b and are arranged in the same direction on a circuit chip 6. The electrodes 1 and 2, weight 3 and beams 4 constituting the sensor chips 100a and 100b have conventional structures and will not be described here in detail.

Here, if the capacity between the electrodes 1 and 2 is denoted by C0, the spring constant of the beams 4 by k, the mass by m, and the distance between the electrodes 1 and 2 by d, then the sensitivity may be defined as follows:

5

Sensitivity $\propto C0 \cdot k/m$

Further, the resilient restoring force of the beams 4 is expressed by $\propto k$, the electrostatic force between the electrodes 1 and 2 is expressed by $\propto 0.5 \cdot C0 \cdot V2/d$, the Z-direction displacement of the moving electrode 1 is expressed by $\propto (k/m)0.5$, and the dynamic range is expressed by $\propto (k/m) 0.5$.

Here, the parameters of a lower sensitive sensor chip illustrated in Figs. 3A – 3C are denoted by $k1$, $C01$, $m1$ and $d1$. Figs. 5A – 5C are also considered below in an attempt to improve the sensitivity of the sensor chip twice as much. The equivalent circuit for the sensor chip of Figs. 1A – 1C is shown, for example, in Fig. 6. If the spring constant = $k1$ is softened, then sensitivity is defined as follows:

Sensitivity $\propto C01 \cdot (2 \cdot k1)/m1 = 2 \cdot \{C01 \cdot k1/m1\}$

Therefore, the sensitivity is improved by a factor of two. In the above discussed related art, however, the resilient restoring force of the beams 4 is halved. Therefore, if its balance relative to the electrostatic force between the electrodes 1 and 2 is taken into consideration, the sticking easily occurs and the displacement of the moving electrodes 1 in the Z-direction is doubled. Accordingly, the moving electrodes 2 tend to ride on the fixed electrodes 1.

On the other hand, the sensor chips 100a and 100b of the constitution illustrated in Fig. 1 have the same characteristics as those of Figs. 3A – 3C, preventing the sticking or the riding of electrodes, and enabling the sensitivity to be improved twice as much without narrowing the dynamic range.

When the output of a single sensor is doubled, the noise component, too, is doubled and the S/N ratio does not vary. According to this embodiment using two sensors, however, the output of signal component only is doubled while the noise component remains unchanged. Therefore, the S/N ratio is improved twice as much (noise occurs in a random fashion and is not superposed).

In Figs. 1A - 1C, there were employed two sensor chips 100a and 100b having the same structure and the same characteristics formed in semiconductor substrates 10a and 10b. As illustrated in a plan view and sectional views of Figs. 2A - 2C, however, it is also allowable to use a sensor chip 100 having two sensors 100a, 100b of the same structure formed in one semiconductor substrate 10 in the same direction. The equivalent circuit for such a sensor chip 100 is shown, for example, in Fig. 7. However, the equivalent circuits of Figs. 6 and 7 could be applied for either of the sensor chips of Figs. 1A and 2A.

It should be noted that the number of the sensors is not limited to two and may be three or more. Further, a plurality of sensors may be stacked on the semiconductor substrate 10 or on the circuit chip 6. In this case, the sensors may be arranged on both surfaces of the semiconductor substrate 10 or the circuit chip 6.

The description of the invention is merely exemplary in nature and, thus, variations that do not depart from the gist of the invention are intended to be within the scope of the

invention. Such variations are not to be regarded as a departure from the spirit and scope of the invention.